

## Pressure versus Force: Landing on Ice!

### Overview

In this activity, students experiment with the relationship between pressure, force, and area. They determine the force and pressure exerted by a De Havilland DHC-6 “Twin Otter” airplane on the sea ice at the North Pole. Twin Otters are commonly used for cargo and personnel transport within the Arctic Circle. *This activity includes components of a classroom activity originally written by Carole Bennett and later modified by her for inclusion in the [National Science & Technology Week 1998](#) resource guide "Polar Connections".*



*De Havilland DHC-6 “Twin Otter”*

### Rationale

Designing an airstrip on land is challenging. Designing airstrip on ice adds a few wrinkles. And to further complicate the engineering, make that ice a slowly moving ice floe! The pilots must know the pressure exerted by the Twin Otters on the sea ice to know if the planes can land safely. A mistake can mean that the plane and cargo break through the ice and end up in the cold ocean below the ice.

### Grade Level/Discipline

Middle or High School, Physical Science

## Objectives

Students will:

- explore the relationship between pressure, force, and area
- strengthen estimation skills

## Teacher Preparation for Activity

Before class, prepare one pan of sand for each group of 4 to 5 students. Pour fine sand into the pan so that each pan has 5 to 10 centimeters of sand in the bottom. Add enough water to dampen, but not soak the sand. There should be no standing water in the pan. The sand should be damp enough so that a finger can be poked into the sand and the hole remains intact when the finger is removed.

### *Materials*

For the teacher:

- A pair of high heel shoes or dress shoes with a distinct heel
- A pair of flat walking shoes or tennis shoes

For each group of 4 to 5 students:

- dish pan or similar container
- fine sand to fill the bottom 5-10 cm of the pan
- water to dampen the sand
- newspapers to place under the pan to restrict the mess
- damp towel to wipe the shoes
- pencils
- paper
- calculator

### *Time Frame*

1 class period

## Teaching Sequence

### *Engagement and Exploration (Student Inquiry Activity)*

Provide each student group with a pan of damp sand, newspapers, and a damp towel. Ask the students to level the sand and pat it down to make it firm.

Tell the student groups that one group member in high heels or dress shoes will step on the sand. What will the imprint look like? The students will then re-level and re-pack the sand and a second student in tennis shoes will step on the sand. What will the imprint look like? How will the two imprints be different? Have each student group record their hypotheses and then perform the experiment. Remind the students to record the results of the experiment. Were the results different from the hypotheses?

### *Explanation (Discussing)*

As a class, discuss the findings of the student groups. Which footprint was deeper, the shoe with the heel or the tennis shoe? Is there a consensus? Can the students explain the results?

The students may say that the individual wearing the high heel weighed more than the student wearing the tennis shoe. How can this be tested so that weight is not a factor? The students may suggest that one person repeat the experiment with high heels or dress shoes and with flat heels. The facilitator can demonstrate this by repeating the experiment using different shoes. What are the results of this experiment? Why is there a difference? What is different about the two shoes? The students should realize that the dress shoe has less area than the tennis shoe. The weight of the teacher was distributed across that area.

This relationship can be expressed as:

$$\text{Pressure} = \text{Force} / \text{Area}.$$

As a class, use the equation to determine the pressure exerted by an 8000 lb. elephant versus a 200 lb. person. Which do the students think will exert more pressure? Which would the students want to have step on them?

The elephant keeps at least 2 feet on the ground when it walks. If you estimate each foot to have 40 in<sup>2</sup> area, it exerts 8000 lb./ 80 in<sup>2</sup> or 100 psi.

Humans will only have one foot on the ground while walking. Estimate that the area of the heel on a man's shoe is 10 in<sup>2</sup>. When he walks, a 200 lb. man exerts 20 psi because the weight is supported momentarily by the heel. A 100 lb. woman exerts many more psi when she wears heels. Depending on the area of the heel, she can exert as much as 1600 psi under a "stiletto heel" 1/4 inch on a side. This explains why people with wood floors don't want women walking on them in high heels.

### ***Elaboration (Polar Applications)***

At the North Pole, there are no paved runways, so planes land on the ice. How might the planes be modified to land on ice rather than pavement? Some of the students may suggest that the planes land on skis, rather than wheels. Ask them how this could make a difference? Which will produce the largest pressure - skis or wheels?

Ask the students to make some estimates about the area of the skis and the wheels. How about the weight of the plane? Just based on the area, can the students make a prediction of the order of magnitude difference there may be (the area varies - the weight of the plane does not)?

Have students work in groups to solve the following questions:

What is the pressure under the skis when the plane lands? What is the pressure under the wheels? We consider only the force and pressure exerted when the plane rests on the ice, not the extra forces created while it lands.

Average weight of a loaded Twin Otter: 10,000 lb.

Area of wheels where they touch the ice:  
2 main wheels: 12 inches x 8 inches each  
nose wheel: 12 inches x 8 inches

Area of skis:

2 main skis and 1 nose ski (12 inches x 30 inches each)

Which should be used to land on sea ice? Why?

Solution:

Average weight of a loaded Twin Otter:

10,000 lb.

Area of wheels where they touch the ice:

2 main wheels 12"x 8" + nose wheel 12"x 8" = 288 in<sup>2</sup>

Area of skis:

2 main skis and 1 nose ski ( 12" x 30" each) = 1080 in<sup>2</sup>

Pressure under wheels

10,000 lb. / 288 in<sup>2</sup> = 34.7 psi

Pressure under skis

10,000 lb. / 1080 in<sup>2</sup> = 9.3 psi

### ***Exchange (Students Draw Conclusions)***

As the ice softens in summer, the ice is unable to withstand the pressure exerted by the wheels and the planes must be adapted to skis. What does this mean for the use of the equation: Pressure = Force/Area?

The skis have a greater area than the tires. By using skis the pressure is about a quarter of the former pressure.

### ***Extensions***

This activity can be modified by having the students think what the pressure must be in the tires of the family car (at least 86.6 psi).

Before the class begins the activity, ask the students to estimate the weight of the family car, the area of tire in contact with the ground, the pressure of each tire. Have the students note their estimates for later comparison.

For homework, ask the students to:

1. Determine the surface area where each wheel contacts the ground by placing string snugly around the wheel-ground interface.
2. Determine the pressure in EACH tire using a tire gauge.

Were the student estimates close to the actual values? Once the students have acquired the appropriate information, calculate the weight of the family car:

3. Since  $P = F/A$ , multiply the area of each tire by its pressure to determine the force (weight) exerted by the car through that tire.

4. Add all the forces (weights) and compare with the manual. It usually is pretty close.

### **Authors**

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### **Background**

The Twin Otter, a twin-engine, modified and enlarged version of the Otter, was a successful attempt to produce a commuter airliner with parts in common with the Otter. As with all good Canadian utility aircraft designs, Twin Otters can be fitted with wheels, skis or floats. Though designed and used as intercity commuter or feeder liners, they are also operated as bush airplanes in deserts, mountains, and the Arctic, or anywhere where rugged reliability and short-take-off-and-landing capability are required.

### **Resources**

- U. S. Navy, VXE-C Public Affairs Officer, Lt. Susan Merriman;
- Courtney W. Willis, Univ. of Northern Colorado, Greeley, CO
- Dr. Mary Ann Davis, Tampa, Florida
- The United States in Antarctica; Report of the U.S. Antarctic Program External Review Panel, 1997